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Intelligent Processing for Primary Metals

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[2]Some divisions within the center are located at Boulder, CO 80303.
[3] Located at Boulder, CO, with some elements at Gaithersburg, MD.

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Intelligent Processing for Primary Metals

Report of Workshop: August 29–30, 1989
Gaithersburg, MD 20899

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INTRODUCTION

A Workshop on Intelligent Processing for Primary Metals was convened on August 29-30, 1989 at the National Institute of Standards and Technology, Gaithersburg, Maryland. It was sponsored by the American Iron and Steel Institute (AISI), the Department of Energy (DOE), and the National Institute of Standards and Technology (NIST). Attendance was by invitation and the more than 80 participants were primarily senior technical staff and managers from steel, aluminum, and copper companies.

The past 5 years have witnessed extensive advances in the enabling technologies needed for intelligent processing of materials. These include: advanced sensors for on-line monitoring of material and process parameters, the knowledge base and materials characterization techniques to develop process models relating process parameters to material properties, and hierarchical computer control strategies for implementing artificial intelligence/expert systems concepts. Several recent national programs have been initiated to integrate elements of these advances to control the processing of advanced materials such as gallium arsenide crystals, powder metals, and composites. Similar opportunities appear to exist in the primary metals industries.

The goal of this industry-led workshop was to highlight the recent advances in sensing, modeling, and process control, to identify areas of need in the primary metals industries, and to develop a strategy for implementation of research results. Industry, university, and government participants assessed information provided by researchers and operating staff from industry to develop a research agenda for coupling the advancing state of materials processing in the primary metals industries. This report is the proceedings of the deliberations from this Workshop. The summaries of the three working sessions were produced by the session chairmen from their notes.

The genesis of this workshop may be traced to two events. First, the signing into law in late 1988 of the Steel and Aluminum Energy Conservation and Technology Competitiveness Act that authorizes DOE and NIST to carry out coordinated programs in support of the primary metals industries, primarily steel, aluminum, and copper. As authorized in this Act, DOE would focus on cost-sharing projects in priority R & D areas, including, but not limited to: direct production of liquid steel, production of near-net shape products, the development of advanced coatings for steel, and the application of automated processing technology. NIST would concentrate on providing instrumentation and measurement R & D.

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The second event was the January 1989 forum at Northwestern University to identify long-range research opportunities for the North American steel industry. The industry participants concluded that research opportunities could best be addressed in the context of three specific long-range development projects: direct production of liquid steel, near-net shape casting, and finishing and coating operations. Further, it was recognized that the successful integration of these three contiguous unit operations would yield important benefits by responding to the increasing constraints on traditional batch processing, by developing new product properties to match customer needs, and by taking advantage of this era of computational plenty to control processes for increased efficiency and product quality.

To capitalize on these events, planning was initiated through a steering committee with representatives from steel, aluminum, and copper trade associations, individual companies, the academic community, and Federal agencies. The consensus was to address the process control needs of the broad spectrum of primary metal industries and the role of intelligent processing concepts in solving these needs by focusing on three generic areas: primary metal production/refining, production of near-net shape products, and finishing/coating to final properties. Emphasis would be on future, advanced processes and technologies.

The workshop was organized into three working sessions:

    I.   Direct Liquid Metal Production

    II.   Near-Net Shape Casting

    III.   Finishing and Coating

Within these areas, the key elements of intelligent processing were stressed. The relationships between fundamentals and processing were explored through the integration of process modeling, sensor technology, and control strategies.

Although the strategy was to achieve a workshop relevant to steel, aluminum and copper, the program contained a strong orientation toward steel-related issues. Since early in this decade, the steel industry has worked to develop a consensus on technical advances needed to improve traditional production practices and on identifying the future steel-making technologies. The steering committee recognized that the steel industry would be particularly well-positioned to play an important role and make major contributions to the workshop.

The Organizing Committee was pleased to have participation by representatives of the aluminum and copper industries because the workshop structure is applicable to the processing of these metals. An overlap or commonality of process control needs is likely in some areas of processing. The success of this workshop could lead to other industries using this approach to develop process control priorities.

Leading off the first day of the Workshop was an introduction to intelligent processing of materials concepts through applications to aerospace and other advanced materials followed by an overview of the process control research needs for the production of steel and aluminum. The workshop format, organized into three working sessions responsible for Direct Liquid Metal Production, Near-Net Shape Casting, and Finishing/Coating, took place in the afternoon of the first day and the morning of the second day to permit a wide range of inputs from the participants. Coordinated presentations were given in these working sessions on the status of sensors, process models, and control approaches, the available technology, and the benefits to relevant research. After the morning sessions on the second day, a brief, verbal synopsis of the deliberations in each of the three working sessions was presented to the assembled workshop participants.

The following three sections, prepared by the co-chairmen of the working sessions, contain the more detailed summaries of the discussions, including the consensus reached on specific topics and recommended actions. The complete list of participants in each session is found in the Appendix.

DIRECT LIQUID METAL PRODUCTION

Session Co-Chairmen

Alan W. Cramb, Carnegie-Mellon University
Jan Kor, Timken Company

Speakers

J. Kor, Timken Company
P. Koros, LTV Steel Company
J. Fay, ASARCO, Inc.
A. McLean, University of Toronto
D. Hardesty, Sandia National Laboratory
C. Alcock, Notre Dame University
Y. Kim, Lehigh University
R. Guthrie, McGill University
M. Shah, IBM
S. Ray, NIST

BACKGROUND/OBJECTIVE

A new generation of processes for direct liquid metal production is evolving. These processes will be continuous rather than batch and involve fewer processing steps, resulting in substantially lower capital and operating costs.

The objective for this session is to define the role that modern techniques for intelligent processing, i.e., sensors, modeling, and computer process control, should play in these major process developments. Based on this assessment, specific recommendations should be made for further cause of action.

The session was organized into two parts: the first part was an information exchange between experts on sensor technology, process control, modeling, and the application of advanced computer decision making techniques[1], while the second part was to define and prioritize specific needs in the area of intelligent processing of liquid metals.

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[1]This phrase used instead of terms "artificial intelligence" and "expert systems" which were overused in this context.

Three major thrust areas were determined: Sensors, Process Modeling and Intelligent Processing. Within each area specific needs were identified. The sensor area was considered to be the area of highest importance and it was the consensus of the group that sensor development and implementation should be the major focus of any endeavor.

SENSORS

Three separate groups of sensors were distinguished: continuous temperature sensors; continuous chemical sensors for liquid metal and hot, dirty gases; and, physical sensors to measure reaction intensity.

Continuous Temperature Measurement

This is an area of immediate need. Discussions indicated that this is not necessarily a problem of temperature measurement itself but more a problem of sensor life in the steel-making environment. It was noted that reactions at the metal/slag interface can be particularly severe when continuous liquid steel measurements are made, and that abrasion in hot, dirty gases can also be a problem. The capability of continuous liquid metal temperature measurement at temperatures between 1450 °C and 1700 °C to an accuracy of plus or minus 1 °C is necessary, while hot gas temperature measurement must be available up to temperatures of 1800 °C.

Continuous Chemical Sensors for Gases and Liquids

This is another area of immediate need and a list of identified sensor needs is given in table 1. Highest priority was given to continuous carbon determination; however, carbon monoxide, carbon dioxide, hydrogen and water contents of the off-gas were also given a high priority. Both of these sensor needs are immediate. A carbon sensor capable of measuring carbon from 0.005 to 4.0 weight percent would be optimum and cover all needs; however, a sensor capable of 0.1 to 4.0 percent would be a good starting point for process control. In gas chemical analysis the major anticipated problems were related to continuous sampling of the hot, dirty gas.

Physical Sensors of Conditions in the System

This area of need is again immediate from the point of view of reaction control; however, since an appropriate sensor could not be identified[2], it was felt that this may be a longer term development. The goal of this sensor development is to develop a real time, on-line measurement of reaction intensity within the bath. A vessel sensor, using some physical measurement which can be made either on or within the vessel (such as a sonic or vibrational measurement) would then be interpreted to give an index of reaction intensity. It was agreed that any such sensor development would need tandem development of appropriate computerized pattern recognition techniques to be successful in a reasonable time frame. "Neural Networks" were mentioned in this context.

MODELING

The area of process modeling was identified as the second most important area for research at this time. Two separate groups of needs were outlined:

(1) Process Control Models
(2) In-Detail Process Models.

Process Control Models

Due to the nature of a continuous reaction vessel, the need was identified for simple on-line process control models, based on sensor and operator input, which will control the operation and act as an operator guide. This is an area of immediate need and the system would be upgraded and developed during pilot plant operation.

In-Detail Process Models

A long range need was determined in the area of process modeling. Although a complete, fundamental heat, mass and fluid flow model of the process was not thought to be realistic, certain portions of the problem were worthy of independent development. Such portions were: heat, fluid flow, droplet size distribution in the foaming emulsion, bubble surface area, jet penetration and solids behavior.

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[2]A number of ideas, documented in table 2, were discussed.

INTELLIGENT PROCESSING

In the area of Intelligent Processing there was a concern that current "Artificial Intelligence" techniques might not be applicable to on-line control in a broad sense; however, in certain well-defined circumstances it may be useful. In addition, it was felt that the computer science involved in process control and decision making was sufficiently rapid that a mechanism should be set up so that appropriate advances can be implemented within the industry in a reasonable time frame. Three separate groups of needs were identified.

Operator Feedback and Instruction

This group is tied to the first group under MODELING. It was felt that "Artificial Intelligence" techniques might be appropriate in operator guidance systems.

System Integration

A problem identified generally with the implementation of computer techniques was standardization and portability. It should not be necessary for each company or plant to custom design their own systems. A group needs to be set up to develop and recommend standards in system integration. Appropriate areas of endeavor are communications, estimation techniques and numerical data bases.

Technology Transfer

To combat the problem of imminent development of appropriate computer technologies, it was felt that a "watch-dog" group should be set up to monitor emerging technologies and to act as a center of technology transfer when appropriate. It was felt that this group should be dynamic, i.e., a group that would be aggressive in attempts to find collaborators interested in industrial development of advances and also be involved in such implementation. The group would also become a center of knowledge in this area and a resource to the industry.

FINAL COMMENTS

The following recommendations emerged from a more general discussion at the end of the workshop:

o Groups should be set up which are multidisciplinary and focussed on a defined task, e.g., a team of sensor, refractory and control specialists should be given the task of developing a continuous carbon sensor which would be fully operational within 2 years.

o A team approach to "intelligent processing" should be initiated early in the project and knowledge integration should be emphasized.

o Research teams should be encouraged, where feasible, to develop generalized approaches and solutions, including computer software, to enhance applicability in the broad area of metal smelting and refining.

o All potential spin-offs should be well publicized and aggressively pursued.

In addition, a participant from a copper company (J. Fay) closed the session by stating that many of the sensors highlighted during this meeting would also be of use to the copper industry[3] and that although the sessions had focused on in-bath smelting the outcome could have more widespread applicability.

<div align="right">

Prepared by: Alan W. Cramb
Jan Kor

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[3]See table 3.

Table 1. Necessary Chemical Sensors

Carbon Content of Liquid Metal

Oxygen Activity of Liquid Metal

Sulfur Content of Liquid Metal

Carbon Monoxide Content of Gas

Carbon Dioxide Content of Gas

Water Content of Gas

Hydrogen Content of Gas

Nitrogen Content of Gas

Slag FeO Content

$Fe^{3+}\backslash Fe^{2+}$ ratio of slag

Table 2. Potential Physical Sensor Techniques

Vibration

Ultrasonics

Static Pressure

Acceleration

Refractory Life

Table 3. Sensor Needs for Copper Industry

Bath Level Measurement

Continuous Temperature Measurement*

Continuous Chemical Analysis of Matte and Slag*

Flame Length Measurement

Refractory Life*

Matte-Slag Interface

Off-Gas Composition*

Solid Feed Rate Measurement

Vessel Content (weight, etc.)

*denotes sensor need area to be similar to in-bath smelting needs.

NEAR-NET SHAPE CASTING

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Richard Sussman, ARMCO, Inc.

Speakers

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R. A. Gleixner, Battelle Memorial Laboratories
L. T. Shiang, Inland Steel Company
Y. Sahai, Ohio State University
H. N. G. Wadley, University of Virginia
J. A. Walton, ARMCO, Inc.

BACKGROUND/OBJECTIVE

The Near-Net Shape Casting session was organized with the realization that several research efforts are underway within North America, indeed worldwide, investigating different casting concepts. No single method has emerged as significantly more advantageous than the others. Accordingly, the principal objective of this session was to determine whether there are common needs that could lead to research projects that would serve a broad constituency in this subject area. The areas of opportunity could include sensors, controls, mathematical and physical modeling, and issues relating to final product properties.

This session was conducted in two parts, according to the agenda shown in the Appendix of this report. The first day was characterized by astute presentations made by experts in their respective fields. Each presentation generated a modest number of questions within the subject area. It is noteworthy that no process-specific problems were detailed during the first-day presentations, to the disappointment of some of the participants. It was emphasized that the intent of the first-day session was to present a broad overview of the subject area, with concentrations on specific problems slated for discussion the following day.

The second day of this session was started by brief presentations made by individuals having hands-on experience with near-net shape casting of metal. Despite the obvious differences between the various casting methods, needs were categorized into three distinct areas: liquid metal handling, casting, and strip collection. With these categories, numerous needs were cited for each of the different processes, many of which were similar from one process to another.

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The discussions showed a clear understanding of the need for the development of specific on-line sensors which could provide necessary real-time information on process variables. Some needs in the areas of modeling were identified; these were more general in nature. There was little expression of need for (or understanding of) intelligent control systems. The lack of comprehensive understanding of near-net shape casting processes is clearly reflected in these latter areas.

SENSORS

Eight sensors were identified as critical to the successful development of a commercial strip casting process. It was recognized that each of these must be employed in a manner in which it could be actively used to control the outcome of the process, and not merely in a passive role to provide information. Attempts were made to determine the range and precision needed for each of the sensors. In many cases, the identified range was quite accurate, but the estimated precision reflected that required of the product; the sensor may require greater sensitivity. For example, if the thickness of a strip is required to be controlled to within 2 percent of its nominal thickness, the measuring sensor must be able to detect a variation of possibly one tenth of that amount in order to effect proper control. The sensor needs were prioritized as follows:

1. Rapid On-line Strip Thickness and Profile Sensing
       - Short time constant, 20X today's technology
       - +/- 2% of nominal thickness, edge-to-edge

2. Liquid Metal Level Sensor
       - +/- 2 mm

3. Continuous Temperature Mapping of the Substrate Surface
       - +/- 5 °C

4. On-line Hot Strip Inspection System

5. Liquid Metal Inclusion Sensor

6. Continuous Temperature Measurement of the Melt
       - +/- 1 °C

7. Continuous Topography Sensing of the Substrate
       - 20 to 200 microinches

8. Liquid Metal Nitrogen Sensor

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It bears repeating that the specifications listed with each of these sensors reflects the limits of control that must be met to produce satisfactory strip. The participants agreed that additional investigation of each of these sensors is necessary to determine operational specifications required of each. The discussions were specifically steered away from including potential solutions to each of the needs; this was not the intent of the session.

MODELING

In the area of mathematical modeling, it was agreed that most models are process-specific. Nonetheless, there exist many commercially available models of the two principal phenomena involved in near-net shape casting, heat transfer and fluid flow. It was determined after considerable discussion that the industry would benefit from a comprehensive review of such models currently available, along with their respective strengths and weaknesses, and a strategy for implementation of selected models. Such a review would assist research groups undertaking projects in this area.

INTELLIGENT PROCESS CONTROL

In the area of process control, it was recognized that the overall state of knowledge of near-net shape casting makes it difficult to design a comprehensive control system at this stage of development. It was determined that it would be meritorious to undertake an intelligent process simulation project to serve as a model for the metals industry. Such a project would introduce many of the features of intelligent processing to the primary metals industry, while simultaneously assist in defining the specifications required for specific sensors.

An extension of this project might involve commissioning the development of an expert system shell, specifically designed for strip casting. It was overwhelmingly agreed that it would not be desirable to attempt to modify an existing shell designed for another process.

FINAL COMMENTS

The interactive discussions that accompanied the session led to the clear observation of the necessity for industry to take the lead role in defining the specifications required of each sensor, particularly in regard to the constraints imposed by the operating environment.

Shortly, after the close of the Workshop, correspondence was received from a participant from the copper industry (B. G. Lewis) expressing observations of similarities and differences between the perceived need of the copper and steel industries. These observations are summarized in table 1.

Prepared by: W. Eugene Eckhart, Jr.
Richard Sussman

TABLE 1. Copper-base Alloys: Near-Net Shape Casting

Process Control Needs:

| Process Details | Sensors/Modelling/Control | PRIORITIES* | |
		Copper Industry	Steel Industry
Melt Furnace	Accurate continuous temperature sensor.	H	M
	Fast/continuous chemical analysis.	H	M
	Inclusion monitor.	M	H
Transfer Launder	Accurate continuous temperature sensor.	H	M
	Dissolved oxygen analysis.	H	L
	Melt level sensor.	M	M
Mold	Melt level sensor.	H	H
	2D mold temperature sensor.	H	H
	2D melt temperature sensor.	H	H
	In mold friction force sensor.	H	M
	Air gap sensor.	H	M
	Liquid/Solid interface sensor.	M	M
	Mold distortion sensor.	M	M
	Model of the melt delivery system.	H	H
	Fast 3D Model combining fluid flow, heat transfer, solidification.	H	M*
Submold	2D Cast strip temperature.	H	H
	2D strip thickness measurements.	H	H
	2D on line strip inspection of surface and bulk quality/uniformity.	H	H

* The high thermal conductivity of copper
   alloys requires 3D thermal analysis.

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FINISHING AND COATING PROCESSES

Session Co-Chairmen

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A. Van Clark, Jr., NIST

Speakers

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P. Southwick, Inland Steel
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J. Monchalin, IMRI Canada
A. V. Clark, Jr., NIST
L. Lowry, Jet Propulsion Laboratory
A. Meystel, Drexel University

BACKGROUND/OBJECTIVE

The finishing and coating processes of the future will become continuous and will be flexible to meet the changing market needs. The objectives of this session of the Workshop were to:

1. Define which intelligent processing technologies can be utilized to enhance product/process development, and to achieve high levels of control and optimization.

2. Recommend specific directions necessary for the formulation of future research programs to develop and apply these technologies in the finishing and coating processes.

The session consisted of two meetings designed to facilitate interaction between national experts and industry experts. The goal of the first meeting was to understand and assess the states of knowledge in intelligent processing; namely, product/process knowledge, process modeling, sensors, integrated process control, and artificial intelligence. The product/process relationships for steel substrates and coated steel were presented along with the needs for future improvements. Subsequent presentations were in sensor development, process modeling, and advanced control. The goal of the second meeting was to address the issues and resolutions that can enhance the success of future research programs to develop and

apply intelligent processing technologies. Finally, summary and recommendations of the overall session were formulated and general consensus obtained at the conclusion of the session.

The major thrust that emerged was the need for integration of metallurgical knowledge with intelligent processing technologies; namely, sensor, process model, and advanced control. The development of identified sensors was perceived to be of the highest priority, since some sensors can have significant and immediate paybacks on the existing processes. Project team formulation, technology transfer, customer requirements were cited as the issues that must be addressed to enhance the success of future Research programs. Specifically, the group recommended that future efforts be focused on intelligent processing of hot-dip galvanizing process. The details of the summary and recommendations are as follows.

SENSORS

Although there is a wide range of sensor needs in the finishing and coating processes, five sensors listed below were identified as having highest priority. Further attempts to prioritize among the five or to define specific ranges and accuracy of the sensors were considered inappropriate by the group because sensor requirements must be specified as an integral part of process modeling and control system development. Attempts were made, however, to estimate the developmental time for the sensors based on current understanding of available principles and technologies. The five sensors are:

1. Continuous Measurement of Temperature of Strip [S][4]
   - Highest priority should be directed to the exit point
   from the post-galvannealing furnace where the strip exhibits low and
   widely varying emissivity.

2. On-line Measurement of Chemical Composition and Phase
   Identification in Coating [S]
   - iron, zinc, and intermetallic phases

3. Measurement of Surface Topography and Surface Chemistry of
   Strip [S, M]

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[4][S] Short Range 1-2 Years

[M] Medium Range 3-4 Years

[L] Long Range 5+ Years

4.   Measurement of Lubricant Film Thickness [S]

5.   Measurement of Mechanical Properties/Microstructure [S to L]
      - direct or predicted measurement of strength and formability in
      final product

Based on the discussion, it was believed that EMAT[5] technology has been sufficiently demonstrated for R-value measurement to the point that on-line measurement of R-value can be realized within a relatively short time frame. For coating composition measurement, Energy Dispersive X-Ray Fluorescence has shown promise over conventional X-Ray Diffraction and Fluorescence techniques. Even though further investigation is needed in this area, the group believed that on-line measurement of coating composition can also be achieved within a short time frame. Laser-ultrasonic is another technology that has shown promise for phase-transformation and grain size measurements and odd-shape gauging. This technique provides excellent potentials for on-line remote sensing as well.

PROCESS MODELING

In general, product/process relationships for steel substrates are known. However, these relationships need to be further quantified and integrated with sensor information and expert knowledge to form working control systems, i.e., intelligent processing technologies. Engineered surfaces and microstructural engineering were cited as the important areas needing further modeling studies.

In the coating processes, much work is needed to understand and model coating adherence mechanisms for a range of coating materials, steel substrates, surface morphology, and processing parameters. In addition, press performance of coated materials in terms of stampability and powdering characteristics must be studied and modeled.

The significance of knowing the product end-use was emphasized by the industry experts. A concept of "component engineering" was introduced and discussed. This concept requires that customer manufacturing processes and required product properties be understood and the information utilized as the driver to product and process development. For example, formability, weldability, and paint appearance are as essential as corrosion resistance in a coated product for automotive applications.

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[5]EMAT = ElectroMagnetic Acoustic Transducer, an ultrasonic device requiring no medium
    to couple sound from transducer to moving sheet.

Specific modeling needs are:

1. Obtain the state-of-the-art of zinc coating and annealing processes.

2. Development coating adherence and coating mechanism models.

3. Develop engineered product property models for coated and uncoated steel.

4. Develop engineered surface model.

Finally, it was noted that product and process knowledge is the limiting factor to process modeling, not the modeling techniques. As such, no new modeling tools were recommended by the group. However, a need was identified for fundamental studies to measure parameters (such as heat transfer coefficients) which are inputs to the various models.

INTELLIGENT PROCESSING

Intelligent Processing was perhaps the most misunderstood subject of the discussion. For the purpose of this report, Intelligent Processing is defined as the integration of product/process expert knowledge, process models, and real-time sensors into an intelligent control system. As such, Intelligent Processing is not a replacement of expert knowledge, but rather a systematic approach to integrate a range of existing technologies into a working control system to achieve product consistency, design flexibility, and process optimization.

The group believed that Intelligent Processing has definitive roles in the finishing and coating processes, in terms of new product and process design and on-line process control. Specific recommendations are:

1. Develop real-time expert models for control to supplement process models.

2. Develop implementable intelligent processing systems from hot rolling to coating, with emphasis on continuous processing.

Since Intelligent Processing involves implementation and also a wide range of multidisciplinary backgrounds, the significance of project team formation, technology transfer, designed-in safety and maintenance were discussed at length. It was believed and recommended that a project team be formed to include from the start the industry, government, university, and equipment supplier, as shown in figure 1. There was some discussion on whether the customer should have input and should be a part of the project team. However, no resolution was reached. Finally, the incorporation of technology transfer from the beginning of the project was stressed as the key element to achieving a successful development and implementation of the technology.

SUMMARY OF RECOMMENDATIONS

A formation of a broad-based and multidisciplinary project team to develop an implementable Intelligent Processing Technologies for the hot-dip coated product was recommended. The needs identified include the development of key on-line sensors, process models, and integrated process control systems. Both short- and long-term results can be expected, all of which can provide positive impacts to the existing products and processes. The developed technology will enable the processes to be responsive to changes in the marketplace. The technology will have applicability to the production of uncoated products as well. Finally, customer inputs will be essential to the success of the project. However, the proper role of the customers on the project must be further defined.

While the primary focus of the session was the needs of the steel industry, there was also a component directed to nonferrous metals. The relevancy of the recommendation to the copper and brass fabricating industry is shown in table 5 (submitted by B. G. Lewis of Olin Corporation) which suggests areas of need with a high degree of overlap between the two industries.

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Prepared by: Dhani Watanapongse
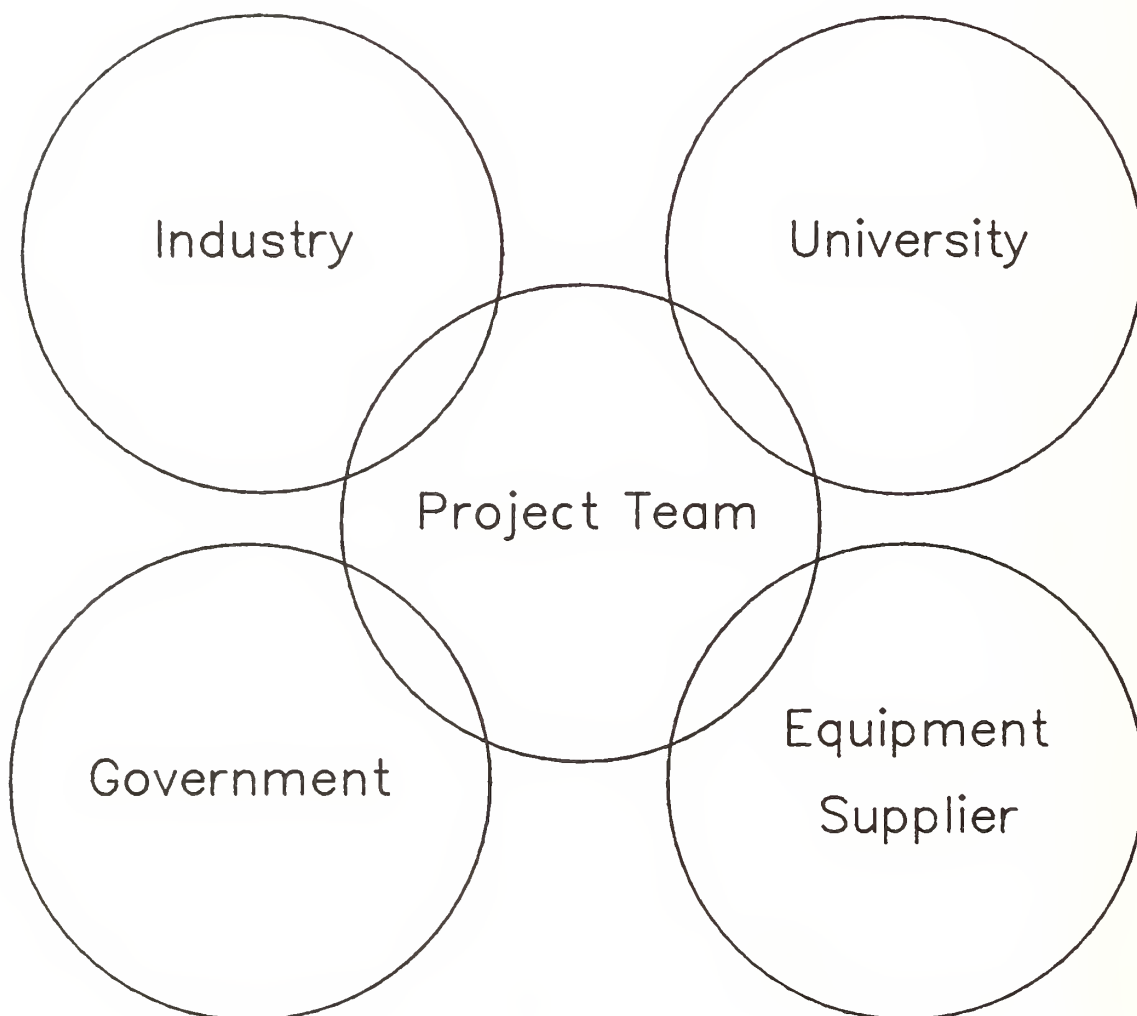A. Van Clark, Jr.

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Figure 1

Project Team Concept

Industry

University

Project Team

Government

Equipment Supplier

TABLE 1. Copper-base Alloys: Finishing and Coating Issues

Process Details	Sensors/Modelling/Control	PRIORITIES[*] Copper Industry	Steel Industry
Hot rolling 6" -> 0.5", batch rolling, 25' bars single strand mill	Monitor temperature through rolling/quenching (emissivity independent). Final structure assessment (uniformity). % IACS for certain alloys. No microstructure based feed back envisioned.	L	M
Coil milling 0.5" -> 0.4", removal of surface oxides and residual casting defects; 20-60 ft/min.	Surface inspection required. Two sided examination for surface defects against a background milling pattern. % IACS for certain alloys.	M	Not Applicable
Cold breakdown 0.4" -> 0.1", tandem mill, 50-500 ft/min.	Surface quality/mechanical defects	L	L
Strip anneal gas heater 15-100 ft/min.	Temperature/temperature distribution Properties[+] (texture, grain size, strength/YS, hardness as determined by recrystallization, stabilization and aging).	H	H
Cleaning Acid cleaning, 20-60 ft/min.	Surface quality (inorganic tarnish). Solderability/toolwear are important properties.	H	Not Applicable
Cold rolling 0.1" -> 0.005", 200-1500 ft/min.	Gauge and width are standard but critical issues. Surface quality (mechanical defects/cosmetics). Properties[+] (as strip anneal, plus formability/internal inclusions).	H	H
Coating Pb-Sn, Sn coatings 1-10 um, 100-300 ft/min.	Coating thickness (not chemistry). Surface topography. In process temperatures.	H	H (galvanizing)

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[*] High (H), medium (M), low (L)

[+] Absolute property measurements are not seen as essential. A measure of product uniformity that is tightly correlated with a property or category of properties would permit the manufacture of product that could be certified according to customer needs off line (static).

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PROGRAM

<u>Monday Evening, August 28, 1989</u>

    6:00-8:00 pm   Wine & Cheese Reception and Registration
                    Gaithersburg Marriott

<u>Tuesday Morning, August 29, 1989</u>

    8:00 am   Bus from Hotel to NIST

    8:15 am   Registration
                   Green Auditorium, NIST

                   COFFEE - *Employees Lounge*

PLENARY SESSION
Green Auditorium

Chairman: Dr. Lyle H. Schwartz   Co-Chairman: Dr. Ian F. Hughes
            National Institute of   Inland Steel Company
            Standards and Technology

    9:00 am   Welcome and Introduction to Workshop
                   - *L. H. Schwartz (NIST)*
    9:15 am   Overview of Intelligent Processing of Materials
                   - *W. Barker (DARPA)*
    10:00 am   Intelligent Processing of Aerospace Materials
                   - *D. Backman (GE)*

    10:45 am   COFFEE - *Employees Lounge*

    11:15 am   Long Range Research - North American Steel's Competitive
                   Edge - *I. Hughes (Inland Steel)*
    12:00 pm   Sensor, Process Models, and Control Needs in the Aluminum
                   Industry - *R. Bonewitz (Alcoa)*
    12:45 pm   Introduction of Session Chairmen/Workshop Instructions - *L. H. Schwartz (NIST)*

    1:00 pm   LUNCH
                   West Square Cafeteria

DIRECT LIQUID METAL PRODUCTION SESSION
Lecture Room D

Chairman: Dr. Egil Aukrust*   Co-Chairman: Dr. Alan Cramb
          AISI Direct Steelmaking   Carnegie-Mellon
          and LTV Steel   University

2:00 pm   Session Objectives and Overview
                - *E. Aukrust (AISI)**

2:10 pm   The AISI/DOE Direct Steelmaking Process
                - *G. J. W. Kor (Timken)*

2:30 pm   Sensor Requirements for the AISI Direct Steelmaking
                Process - *P. Koros (LTV Steel)*

3:00 pm   Sensor Needs in Copper Smelting
                - *J. Fay (ASARCO, Inc.)*

3:20 pm   COFFEE - *Employees Lounge*

3:40 pm   Sensors - *A. McLean (University of Toronto)*, Chairman

                Signals from Molten Metal
                - *A. McLean (University of Toronto)*
                Optical Diagnostics for In-Situ Measurements in
                  Combustion Environments - *D. Hardesty (Sandia)*
                Electrochemical Sensors for Intelligent Processing
                - *C. B. Alcock (Notre Dame University)*
                Continuous Measurements of Molten Metal Composition
                - *Y. Kim (Lehigh University)*

4:30 pm   Process Modeling - Mathematical Models for Metallurgical
                Operations - *R. Guthrie (McGill University)*

4:50 pm   Application of Control Theory and Artificial Intelligence
                in Process Development - *M. Shah (IBM)*

5:10 pm   Architecture and Integration Techniques Used in AMRF
                - *C. McLean (NIST)*

5:30 pm   End of First Day's Session

5:45 pm   Bus to Hotel

---

*G.J.W. Kor substituted for E. Aukrust during Workshop.

NEAR-NET SHAPE CASTING SESSION
Lecture Room B

Chairman: W. Eugene Eckhart   Co-Chairman: Dr. Richard Sussman
           Department of Energy   Armco, Inc.

2:00 pm	Session Objective and Overview - *W. E. Eckhart (DoE)*
2:05 pm	Review of Near-Net Shape Casting of Steel Strip - *M. Moore (USS)*
2:35 pm	Process Control Considerations for Direct Strip Casting of Steel Sheet - *R. Gleixner (Battelle)*
3:05 pm	Product Issues - *K. Blazek (Inland Steel)*
3:30 pm	COFFEE - *Employees Lounge*
3:50 pm	Process Modeling - *Y. Sahai (Ohio State University)*
4:20 pm	Sensor Principles - *H. Wadley (University of Virginia)*
4:50 pm	Artificial Intelligence in Process Control - *J. Walton (Armco)*
5:20 pm	Summary and Preview of Issues - *R. Sussman (Armco)*
5:30 pm	End of First Day's Session
5:45 pm	Bus to Hotel

FINISHING AND COATING SESSION
Lecture Room A

Chairman: Dr. Dhani Watanapongse   Co-Chairman: Dr. A. Van Clark, Jr.
            Inland Steel Company   National Institute of
                                                     Standards and Technology

2:00 pm	Session Objective and Overview	
	- D. Watanapongse (Inland Steel)	
2:10 pm	Process Description, Measurement Status, and Needs	
	- D. Reinbold (Bethlehem Steel)	
2:30 pm	Steel Products by Design: The Challenge of the Future	
	- P. Southwick (Inland Steel)	
2:50 pm	Coating Processes	
	- S. Denner (National Steel)	
3:10 pm	Microstructural Engineering: Models Linking Products and	
	Processes *- K. Brimacombe (University of British Columbia)*	

3:30 pm   COFFEE - *Employees Lounge*

3:50 pm	Laser Ultrasonics: A Novel Sensor Technology	
	- J. Monchalin (IMRI)	
4:10 pm	Measurement of Steel Sheet Formability (R-Value)	
	- V. Clark (NIST)	
4:30 pm	X-Ray Methods for Coating Composition Measurement	
	- L. Lowry (Jet Propulsion Laboratory)	
4:50 pm	Integrated Control with Incomplete Information	
	- A. Meystel (Drexel University)	

5:10 pm   Summary and Preview of Issues
                        - D. Watanapongse (Inland Steel)

5:30 pm   End of First Day's Session

5:45 pm   Bus to Hotel

6:00 pm   Social Hour - Cash Bar
           Gaithersburg Marriott

7:00 pm   Workshop Dinner
           Gaithersburg Marriott

Thomas J. Murrin
Deputy Secretary of Commerce

New Metals Technologies: Making the Government-Industry Connection Work

    7:45 am   Bus from Hotel to NIST

                     COFFEE - *Employees Lounge*

DIRECT LIQUID METAL PRODUCTION SESSION (cont.)
Lecture Room D

Chairman: Dr. Egil Aukrust[*]   Co-Chairman: Dr. Alan Cramb
                 AISI Direct Steelmaking   Carnegie-Mellon
                 and LTV Steel   University

    8:30 am   Session Objectives and Introduction
                     - *A. Cramb (Carnegie-Mellon University)*

    8:40 am   Panel Discussions

                     Sensors - *J. Hoffman (Bethlehem Steel)*, Group Leader

                     Sensor Developments in Steelmaking
                     - *J. Hoffman (Bethlehem Steel)*
                     Problems in Continuous Measurement Applications
                     - *Y. Kim (Lehigh University)*
                         Discussion

                     Integration and Measurements
                     - *E. Swanson (Inland Steel)*, Group Leader
                       Discussion

  10:40 am   COFFEE - *Employees Lounge*

  11:00 am   Intelligent Processing - *M. Shah (IBM)*, Group Leader
                       Discussion

  12:00 pm   Review, Summary, and Recommendations
                     - *A. Cramb (Carnegie-Mellon University)*

    1:00 pm   LUNCH
                     West Square Cafeteria

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[*]G.J.W. Kor substituted for E. Aukrust during Workshop.

7:45 am   Bus from Hotel to NIST

                 COFFEE - *Employees Lounge*

NEAR-NET SHAPE CASTING SESSION (cont.)
Lecture Room B

Chairman: Dr. Richard Sussman   Co-Chairman: W. Eugene Eckhart
            Armco, Inc.   Department of Energy

8:30 am   Review Issues and Expected Outcome
                     - *R. Sussman (Armco)*

8:45 am   Review of Process-Specific Needs

                         R. Sussman (Armco)
                         E. Mizikar (LTV Steel)
                         T. Conarty (Bethlehem Steel)
                         J. Naumann (Allegheny Ludlum)
                         J. McKay (Projet Bessemer)
                         K. Blazek (Inland Steel)
                         T. Gaspar (Ribtec)

10:30 am   COFFEE - *Employees Lounge*

10:45 am   Round Table Panel Discussion

                         Degree of Process Understanding
                         Similarity/Differences Between Processes
                         Mechanism Needed to Integrate Modeling, Sensing, and
                             Controlling
                         Model Plan to Implement Emerging Technology
                         Survivability Requirements of Sensors

12:45 pm   Summary and Recommendations
                     - *R. Sussman (Armco)*

1:00 pm   LUNCH
                     West Square Cafeteria

7:45 am	Bus from Hotel to NIST
	COFFEE - *Employees Lounge*

FINISHING AND COATING SESSION (cont.)
Lecture Room A

Chairman: Dr. Dhani Watanapongse   Co-Chairman: Dr. A. Van Clark, Jr.
           Inland Steel Company   National Institute of
                                                        Standards and Technology

8:30 am	Session Objectives and Overview - *V. Clark (NIST)*

8:40 am	Round Table Discussion: Sensors Development
	    - *D. Tyler (Olin Brass)*, Group Leader
	
	Priorities for Sensor Needs
	    - *C. Romberger (Bethlehem Steel)*
	Probabilities of Success
	    - *T. Judd (LTV Steel)*
	    - *M. Adams (JPL)*
	Sources for Expertise
	    - *B. Thompson (Ames Laboratory)*
	Difficulties of Implementation
	    - *B. Muly (University of Tennessee)*
	    - *T. Munson (Reynolds Metals)*

10:20 am	COFFEE - *Employees Lounge*
10:45 am	Integration of Process Understanding and Modeling - *W. R. D. Wilson (Northwestern University)*
11:15 am	Impact of Rapid Product/Process Changes - *A. Gibson (Armco)*
11:45 am	Management of Multidisciplines - *B. Kushner (BDM Corp.)*
12:15 pm	Technology Transfer to Plant Floor - *W. A. Wilson (Weirton Steel)*
12:45 pm	Summary and Recommendations - *V. Clark (NIST)*
1:00 pm	LUNCH *West Square Cafeteria*

1:45 pm   Laboratory Tour

           Bus to Industrial Building

           - Intelligent Processing of Metal Powders
           - Texture Sensor
           - Aluminum Extrusion Temperature Sensor

SUMMARY SESSION
Green Auditorium

Chairman: Dr. Ian F. Hughes   Co-Chairman: Dr. Lyle H. Schwartz
           Inland Steel Company   National Institute of
                                                        Standards and Technology

3:00 pm   Summary of Direct Liquid Metal Production Session
                 - *A. Cramb*
3:20 pm   Summary of Near-Net Shape Casting Session
                 - *W. E. Eckhart*
3:40 pm   Summary of Finishing and Coating Session
                 - *D. Watanapongse*
4:00 pm   Workshop Relevance to NIST Program Planning
                 - *L. H. Schwartz*
4:20 pm   Workshop Relevance to DOE Program Planning
                 - *T. Gross*

4:40 pm   Workshop Wrap-Up
                 - *L. H. Schwartz (NIST)*

5:00 pm   End of Workshop and Departure

INTELLIGENT PROCESSING FOR PRIMARY METALS
August 29-30, 1989

National Institute of Standards and Technology
Gaithersburg, Maryland

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Session #2: Near-Net Shape Casting
Session #3: Finishing and Coating

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Report of Workshop

5. AUTHOR(S)

Editors: Alan Cramb, W. Eugene Eckhart, Jr., Dhani Watanapongse, James Early, Jan Kor
Richard Sussman, A. Van Clark, Jr.

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11. ABSTRACT (A 200-WORD OR LESS FACTUAL SUMMARY OF MOST SIGNIFICANT INFORMATION. IF DOCUMENT INCLUDES A SIGNIFICANT BIBLIOGRAPHY OR LITERATURE SURVEY, MENTION IT HERE.)

This industry-led workshop highlighted the recent important advances in sensing, modeling, and process control, identified areas of application in primary metals production, and developed a strategy for implementation of research results. Industry, university, and government participants assessed information provided by researchers and operating staff from industry and developed a research agenda for coupling the advancing state of materials processing in the primary metals industries. This report is the proceedings of the deliberations from the Workshop.

12. KEY WORDS (6 TO 12 ENTRIES; ALPHABETICAL ORDER; CAPITALIZE ONLY PROPER NAMES; AND SEPARATE KEY WORDS BY SEMICOLONS)

control strategy; intelligent processing; primary metals; process models; sensors, steel

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15. PRICE

ELECTRONIC FORM

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